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INFLUENCE OF HELICOIDAL CRACK ON DYNAMIC BEHAVIOR OF ROTATING SHAFT

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ABSTRACT

The present study aims at the analysis of vibration characteristics of rotating shaft which contains single helicoidal surface crack. The shaft material is EN8. There are seven shafts out of one is intact shaft other six are helically cracked shafts and of the same material having the same dimensions with a crack orientation of 29^0, 45^0 and 55^0 with the longitudinal axis of rotary. Crack is taken at location 100 mm and 300 mm from bearing side. Crack width is taken as 1 mm and the depth is taken as 1 mm and revolved for 180^0 of shaft diameter which is taken as a total crack length. Vibration response of each shaft is studied with FFT Analyzer for different rotational speeds along with varying loading condition in which disc is attached to the center of the shaft. The readings from FFT analyzer and the experimental set up are validated by using MSC NASTRAN software. The amplitude of vibrations is increased as rotor weight and shaft speed increased for every angle of orientation of helicoidal crack. The trend of higher amplitude observed for 45^0crack orientation.

***KEYWORDS**: Vibration Analysis, Helicoidal Crack, Shaft & MSC Nastran*

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Original Article

INTRODUCTION

The study of cracks and its location is very important as the shaft is the main parameter to transmit power from one point to another point in various industries and also in various machines like a turbine, generator, and aero engines. Failure of a shaft is directly affected on the safety of environment around the machine and transmission efficiency of machines shafts. In this, a study has done on cracks on the solid shaft such as helicoidal cracks. Helicoidal crack may develop due to the combined action of bending and torsion at mid-span of double flow steam turbines in high power turbo-groups. Helicoidal crack is very specific part of the study. The experimental analysis is done using an FFT analyzer and results are compared with model simulation in MSC Nastran.

LITERATURE REVIEW

ZhaohuiRen et. al [1] have personated the study of crack fault diagnosis of rotor systems using wavelet transforms. The 3-D waterfall spectrum in combination with the reassigned wavelet scalogram method is presented to analyze the temporal frequency characteristics of the crack fault. They found that this method is an effective tool to diagnose cracks in rotor system and the frequency characteristic can be used as references in the diagnosis. The vibration characteristics of cracked rotor system have been intensively studied by researchers by applying

experimental methods and numerical simulation technique.

QinkaiHannet. al [4] has analyzed a geared rotor-bearing system with slant breathing crack. In his study vibration problems associated with geared systems has been focused, in which slant crack is likely to have appeared on the working shaft.

Due to this slant crack the dynamic behavior of the cracked geared system had different behavior than an uncracked system. The stress intensity factors, flexibility matrix for slanting crack had derived using fracture mechanics and whirling analysis, parametric instability analysis, and steady-state response analysis three methods were introduced. The effects of crack depth, position and type (transverse or slant) on the system dynamic behaviors were considered in this paper.

R. Ramezanpouret. al [5] has investigated the dynamic behavior of a Jeffcott rotor system with a slanting crack under arbitrary crack orientations. Flexibility matrix and stiffness matrix of the system were calculated in this paper using fracture mechanics. In this paper, a symmetric relation to the global stiffness matrix was presented. Also, investigation on the influence of crack orientations on the flexibility coefficients and the steady-state response of the system had done. The results from this paper indicate that results of flexibility coefficients were greatly varied by increasing the crack angle from 30^0 to 90^0(transverse crack). Maximum values of the flexibility coefficients were observed at 60^0crack orientations.

Ashish K. Darpe [7] has presented a finite element model of a rotor with slanting crack. Based on fracture mechanics, a new flexible matrix for the slanting crack is derived that accounts for the additional stress intensity factors due to the orientation of the crack compared to the transverse crack. Comparison between rotor with slant and transverse crack was made in this paper. He found that larger cross-coupled stiffness values for slant crack had stronger cross coupling in the bending torsional longitudinal vibrations compared to the transverse crack.

N. Bachschmidet. al [11] says in his paper that helicoidal cracks could appear in industrial machine shafts which may develop due to the combined action of bending and torsion at mid-span of double flow steam turbines in high power turbo groups. In this study, they observed that static elastic behavior of a shaft slightly affected by a helicoidal crack so by means of 3D finite element non-linear models they calculated deflections in different load conditions.

By studying and analyzing all the above literature we have focused to study the influence of helicoidal crack on vibration characteristics such as natural frequency and amplitude of rotating shaft, an effect of speed on the dynamic behavior of cracked shaft along with varying loading conditions experimentally. Also, comparing vibration characteristics of a rotating shaft with and without helicoidal crack and comparing experimental & FEA results for modal analysis of shaft.

EXPERIMENTATION

The experimentation is carried out on one intact shaft and six helicoidally cracked shafts with an experimental set up as shown in fig.1. Experimentation is done using the FFT analyzer. The speed variations are taken at 500, 1000 and 1500 rpm for 0.5kg, 1kg and 1.5kg loading conditions for this experimentation.

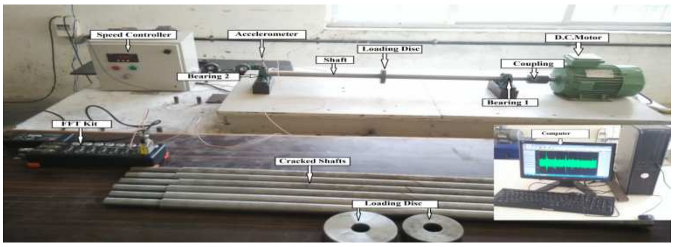

Figure.1: Photograph of Experimental Setup

Parametric Study

For an analysis of the vibrations from a shaft with helicoidal crack orientations, experiments are conducted with a change in various running parameters. Following a combination of experimental conditions, i.e. cases are possible with healthy and helicoidally cracked shafts which are represented in a below tables.

Table 1: Cases about Healthy and Helicoidally Cracked Shafts for Final Experimental Results

Case No.	Description
1	Healthy shafts with speeds 500, 1000 and 1500 rpm with weight variations 0.5, 1 and 1.5 kg.
2	Shaft with speeds 500, 1000 and 1500 rpm with crack orientation 29^0withweight variations 0.5, 1 and 1.5 kg and crack at location 100 mm on shaft.
3	Shaft with speeds 500, 1000, 1500 rpm with crack orientation 45^0withweight variations 0.5, 1 and 1.5 kg and crack at location 100 mm on shaft.
4	Shaft with speeds 500, 1000, 1500 rpm with crack orientation 55^0withweight variations 0.5, 1 and 1.5 kg and crack at location 100 mm on shaft.
5	Shaft with speeds 500, 1000 and 1500 rpm with crack orientation 29^0withweight variations 0.5, 1 and 1.5 kg and crack at location 300 mm on shaft.
6	Shaft with speeds 500, 1000, 1500 rpm with crack orientation 45^0withweight variations 0.5, 1 and 1.5 kg and crack at location 300 mm on shaft.
7	Shaft with speeds 500, 1000, 1500 rpm with crack orientation 55^0withweight variations 0.5, 1 and 1.5 kg and crack at location 300 mm on shaft.

Observed Spectra from FFT Analyzer

Here are some observed spectrum of FFT which shows the behavior of cracked shafts at various speed and loading conditions.

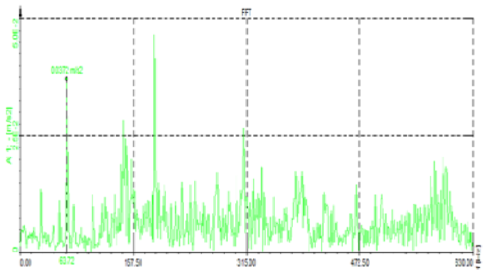

Figure.2: FFT Spectrum for 29^0 Crack at 100 mm for 500 rpm with 0.5kg Wt.

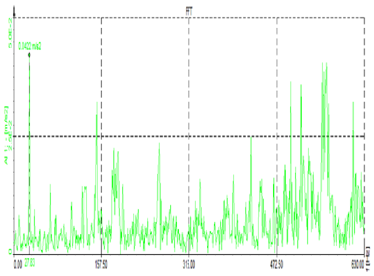

Figure.3: FFT Spectrum for 55^0 Crack at 100 mm for 500 rpm with 0.5kg Wt.

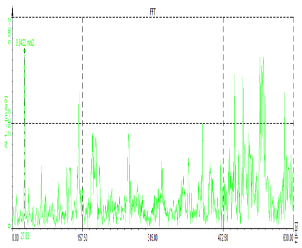

Figure.4: FFT Spectrum for 45^0 Crack at 100 mm for 500 rpm with 0.5kg Wt.

NATURAL FREQUENCY ANALYSIS

The natural frequencies of a structure are the frequencies at which the structure naturally tends to vibrate if it is subjected to a disturbance and the deformed shape of the structure at a specific natural frequency of vibration is termed its normal mode of vibration. The reason to compute normal modes is to assess the dynamic interaction between a component and its supporting structure.

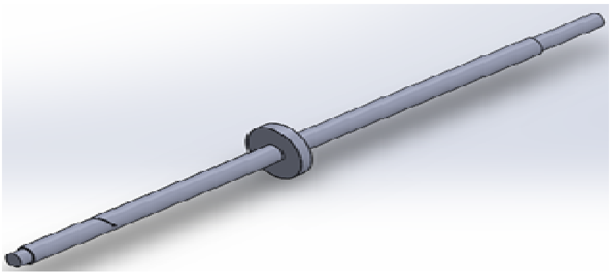

Figure 5: CAD Model for Shaft with Helicoidal 29^0 Cracks at 100mm Dist

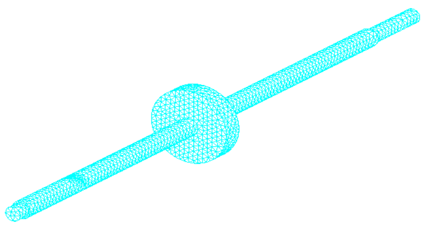

Figure 6: Meshed Model of Shaft with Helicoidal 29^0 Cracks at 100mm Dist.

Mode Shapes of Healthy Shafts

The model analysis is carried out in MSC-NASTRAN2013 and by FFT Analyzer and first three natural frequencies for the healthy and cracked shaft are calculated.

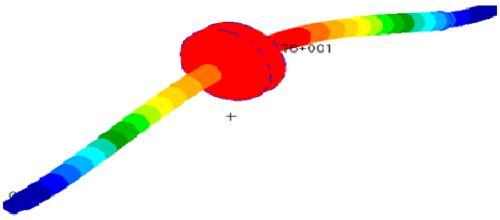

Figure 7: First Mode Shape for 0.5 Kg Disc of Natural Frequency 102.56 Hz

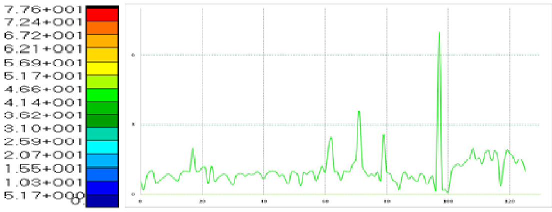

Figure 8: FFT Spectrum indicating First Natural Frequency of 97.21 Hz for 0.5 Kg Disc

Behavior of Natural Frequency

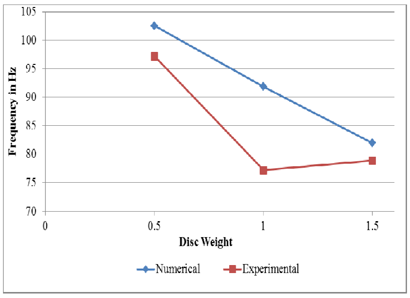

Figure 9: Comparison of Numerical and Experimental First Natural Frequency for All Disc Weight

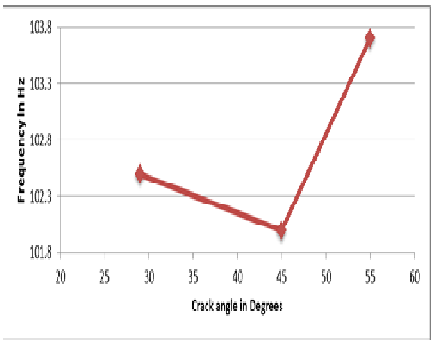

Figure 10: Crack Angle vs. First Natural Frequency for 0.5 kg Disc

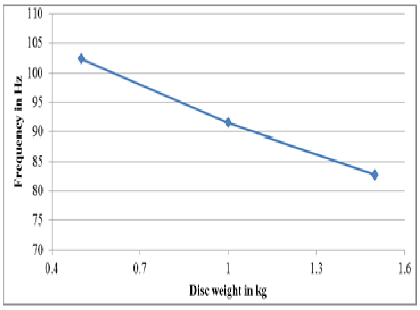

Figure 11: Disc Weight vs. Natural Frequency for 29^0 Crack Orientations

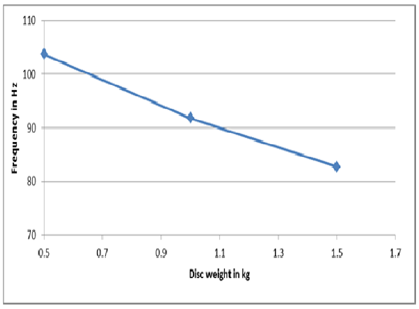

Figure 12: Disc Weights vs. Natural Frequency for 55^0 Crack Orientations

From above figure no. 9, it is observed that the variation in numerical and experimental values of first natural frequency for 0.5 kg disc is 5.068 % and for 1 kg disc, it is 15.98 % and for 1.5 kg disc it is 3.75 % which are in the permissible limit. From figure no. 10, it shows that the natural frequency has decreased for 45^{0}crack but suddenly it has increased to 55^0. The highest first natural frequency has observed for 55^0 crack orientation as compared to other crack orientation. The 45^0 crack orientation gives lowest natural frequency and from figure no. 11 and 12, it is observed that natural frequency decreases as the increase in the system weight. This behavior is not affected by the crack angle orientation and cracks location. The decrease in natural frequency is due to the reason that the natural frequency is a function of weight and various inversely with weight.

EXPERIMENTAL RESULTS AND DISCUSSIONS

This experimentation has carried out for different disc weights (0.5, 1 & 1.5kg) and different speed conditions (500, 1000, 1500rpm) for healthy and helicoidally cracked shaft.

Graphical Representation of Results

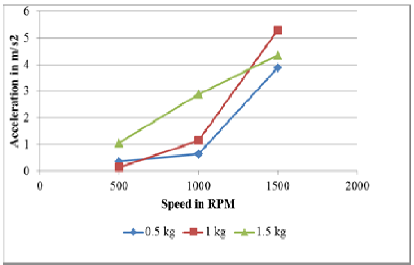

Figure 13: Variation in Acceleration with Speed for Healthy Shaft

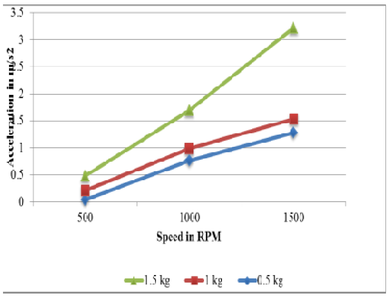

Figure 14: Variation in Acceleration with Speed for 29^0 Cracks at 100mm

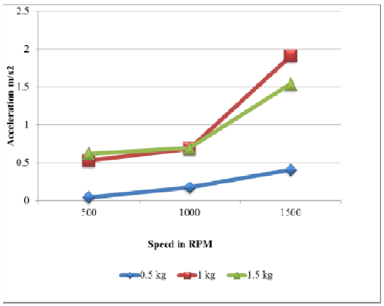

Figure 15: Variation in Acceleration with Speed for 45^0 Cracks at 100mm

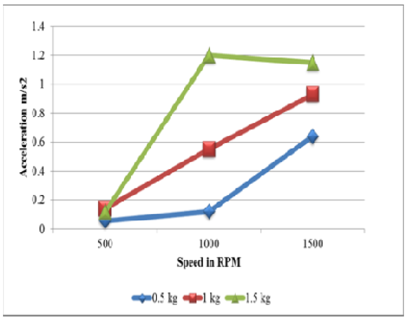

Figure 16: Variation in Acceleration with Speed for 55^0 Cracks at 100mm

The graph for each disc shows an increasing trend of amplitude from 500 rpm to 1500 rpm. The highest amplitude was observed for 29^0&55^0 crack at 100 mm for 1.5 kg disc at 1500 rpm as seen from figure no. 14&15, and same higher amplitude was observed for 45^0 crack at 100 mm for 1 kg disc at 1500 rpm as seen from figure no.15.

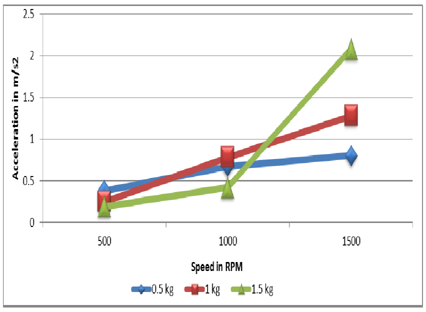

Figure 17: Variation in Acceleration with Speed for29^0 Crack at 300mm

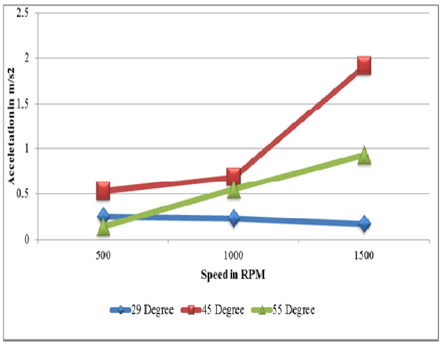

Figure 18: Variation in Acceleration with Speed for All Cracks at 1kg Disc Wt.

There is slightly increase in amplitude for the 29^0helicoidal crack at 300 mm from bearing end compared to 100 mm of bearing end as crack is moved near to load. Figure no. 17 shows that for 1.5 kg disc weight initial amplitude level is low for 500 and 1000 rpm but for 1500 rpm it increase rapidly. The increase in amplitude for 0.5 kg and 1 kg disc load take place with some linearity. Similar graphs can plotted for 45^0 and 55^0 crack orientations for 300 mm location. From figure no. 18, the variation in amplitude for 45^0 crack graph is showing higher amplitudes with the increasing trend for all speed ranges. The 29^0 crack has almost the same amplitude for all speeds and $55^0$is showing learner relationship. This trend of higher amplitude for 45^0 is probably due to the principal stress are acting at 45^0 on a shaft while transmitting torque.

CONCLUSIONS

The natural frequency of shafts decreases as an increase in the system weight. This behavior is not affected by the crack angle orientation and crack location and there are very few changes in the natural frequencies of healthy and cracked shafts. As speed increases the amplitude of vibrations are increased as an increase in rotor weight (0.5 kg, 1 kg and 1.5 kg). From every angle of orientation of helicoidal crack (29^0, 45^0 and 55^0) the amplitude of vibration increases as shaft speed increases. The rotor weight at the center of the shaft gives an increase in amplitude as weight increases for 0.5 kg and 1.kg rotor weight, but for 1.5 kg weight amplitude slight decreases for 1500 rpm. This may have happened due to whirling behavior of the shaft. For 45^0 crack graph is showing higher amplitudes with the increasing trend for all speed ranges. The 29^0 crack has almost the same amplitude for all speeds and $55^0$is showing linear relationship. This trend of higher amplitude for 45^0 is probably due to the principal stress are acting at 45^0 on a shaft while transmitting torque. As the crack is moved near to the load there is slightly increased in amplitude as compared to crack away from the load.

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